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NOVEL APPLICATIONS FOR TAZ-8A

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ABSTRACT

Since the early 1960's the NASA Lewis Research Center has been actively engaged in alloy development for jet engine applications. A series of alloys were developed through "in-house" research. Several significant alloys resulted from this program. One of the most promising alloys is a nickel base material referred to as TAZ-8A. It was selected by NASA as the nose cone material for the Mach 8 version of the X-15 rocket ship.

Recent needs in the non-aerospace industrial sector have revitalized interest in high performance alloys. TAZ-8A has a combination of properties that makes it unique: (a) a high temperature strength, (b) oxidation resistance, (c) abrasion resistance, and (d) exceptional thermal shock resistance. The major drawback for utilization of this alloy is the relatively high cost compared to the more common iron base alloys. Reduced material consumption and hence lowered costs are possible by using coatings of TAZ-8A on a low cost substrate.

Coatings have been applied using plasma spray techniques developed by NASA as well as modified plasma vapor deposition (PVD) techniques.

Unique properties result from each of these two different coating processes. The PVD process results in a thin coherent coating that possesses high reflectivity, extreme hardness, and abrasion resistance. These properties are currently being quantified and offer the potential for a wide variety of commercial applications.

INTRODUCTION

To a large extent the history of the development of gas turbine engines has been a story of the development of high performance materials. The same is true for all "heat cycle" engines. Virtually all of these engines convert thermal energy to mechanical work by heating a working fluid in a controlled volume such that as it expands it exerts pressure against a surface, translating it into a force acting on the machine. The primary source of the heat used in these engines is the heat energy released in the combustion of a fuel. Much of this heat energy is wasted through cooling systems or by exhausting the hot working fluid prematurely, because the materials and lubricants in the engine connot withstand the elevated operating temperatures that would be necessary to fully utilize all of the heat energy generated. As a consequence, scientists and engineers have been working for three hundred years to develop high temperature materials.

In the 1960's scientists, engineers and technicians at the NASA Lewis Research Center developed a family of nickel based "superalloys" employing tantalum as the principal alloying ingredient. The most promising of these was an alloy containing eight weight percent tantalum, called TAZ-8. Further development of the TAZ-8 alloy to improve oxidation resistance produced TAZ-8A, in which columbium was substituted for vanadium in the original alloy (1). The Lewis-developed TAZ alloys became the prototypes of a number of similar high temperature superalloys developed by the aerospace industry.

While the initial "target applications" of TAZ-8A were hot section components of gas turbine engines (such as turbine vanes or "buckets"), other aerospace applications soon appeared. One example is the nose cone of the X-15 rocket plane. In this case the source of the high temperature was the aerodynamic frictional heat buildup at Mach 8 flight.

There are some drawbacks to the utilization of this superalloy. One is its toughness. It is extremely resistant to the normal cutting and grinding processes normally used to machine metal parts to their final shapes. The material can be worked with forming processes based on plastic deformation of the material, such as rolling, but only at very small deformation rates and under very precisely controlled conditions. Considerable work had to be done to develop the necessary manufacturing technologies to use this material. The two principal techniques used are precision casting to near net shape and the consolidation of prealloyed powder.

The other drawback is cost. Some of the alloying elements are "strategic materials", meaning they are rare, difficult to obtain in quantity, and thus expensive. Besides raising the cost, this limits the size of the components and their number. The solution to this problem is to use TAZ-8A as a thin, protective coating on a low cost substrate. This will also bypass many of the difficulties encountered in fabricating complex parts.

It is doubtful that TAZ-8A would be a practical material for use in mass produced consumer products, at the present. Rather it is felt that its major potential at the present time is to improve the performance of key components in industrial processes involving extremely high temperatures, continuous thermal cycling, and abrasive environments. In recent years many American industries utilizing such processes have come under intense competition from abroad. This competition is often in the form of higher productivity rates, leading to lower prices of the final products. One way to improve productivity is to reduce down time by identifying the critical components, the "weak links", and increasing their service lives.

PROPERTIES OF TAZ-8A SUPERALLOY

The nominal composition of the TAZ-8A alloy in weight percent is shown in Table 1. The relative amounts of the constituent elements were determined in an iterative process to optimize them. For example, columbium content was varied from 0.5 to 20 percent, but it was found that stress-rupture life reached its maximum at 2.5 percent and degraded rapidly as the columbium content was increased beyond that level(1).

It should be noted that the manufacturing processes and test conditions used to evaluate TAZ-8A were chosen as characteristic of its anticipated aerospace applications, primarily as a material from which to fabricate hot section components of aircraft gas turbine engines. The initial work was done with investment-cast specimens melted either in an inert gas (argon) furnace or a vacuum furnace. Specimens cast included stress-rupture and tensile test bars, Charpy impact test bars, and blanks for test rolling sheet strips to test workability.

Figures 1 through 7 present high-temperature properties of cast TAZ-8A compared to representative examples of other high-temperature materials used for similar aerospace applications. Representative example data are used rather than data for specific alloys because the aerospace industry has developed a number of different alloys in each generic category, and each alloy has slightly different properties. For the purpose of this paper, "typical" properties for each category are more instructive.

Figures 1 and 2 present stress-rupture data taken at 1800F. The temperature was selected as representative of gas turbine hot-section temperatures at the time the tests were performed. Stress-rupture data addresses the problem of how well the material will hold up under load in a high temperature environment. This is a more realistic approximation of what a machine element experiences than a tensile test.

TAZ-8A is a cast material, and Figure 1 shows what a major impact that controlled solidification of the molten alloy can have on the material's strength. Stress-rupture performance is improved by nearly 40 percent by directionally solidifying the melt. Considerable care is required in the casting process with a highly alloyed material such as TAZ-8A to prevent segregation (the separating-out of the constituents) during solidification, resulting in a part with varying properties.

Figures 3 and 4 present high temperature tensile strength data. The proportional limit is the stress level at which ductile deformation of the test sample initiates. The ultimate tensile strength is the stress level at which the piece fails. Notice that directional solidification reduces the ultimate tensile strength of TAZ-8A, and also lowers the yield point, but at the same time significantly increases its ductility. This would produce a machine part that would be less prone to catastrophic failure.

The number of thermal cycles a standard test bar endures before cracking initiates on its edge is a measure of the material's ability to withstand thermal shocking and repeated hot-cold temperature cycles. Thermal cycling data for TAZ-8A compared to other high temperature alloys are presented in Figures 5 and 6. This material exhibited outstanding thermal cycling resistance in the testing that produced these data. The temperature ranges were selected as representative of aerospace conditions.

Oxidation resistance is another important property for materials used in high temperature applications. Oxidation behavior of TAZ-8A is compared to other representative high-temperature alloys in Fig. 7. Fig. 7a presents weight-gain data after 8 hours exposure at several temperatures. The increase in weight is due to the oxygen takeup by the outer layers as they oxidize. This oxidized scale was then removed; the net weight loss is presented in Fig. 7b.

The TAZ-8A specimens used for the oxidation data in Fig. 7 were vacuum-melted. With samples cast in an inert gas (argon) atmosphere, considerably poorer oxidation resistance was measured, although overall oxidation resistance was judged comparable to other high temperature materials. Table 2 compares oxidation behavior of vacuum-melted and argon-melted TAZ-8A. The difference in oxidation rate appears to be due to a coarser microstructure in the argon-melted material. Photomicrographs of the metal-oxide interface, depletion zone, and unaffected matrix of oxidised stamples of vacuum-melted and argon-melted TAZ-8A showed a thinner depletion zone with a more clearly defined interface between the depletion zone and the unaffected matrix in the vacuum-melted specimens. As in the case of the tensile data, this shows that the processing and fabrication procedures can have a significant impact on the performance of the finished part.

A limited workability potential of the cast TAZ-8A material was demonstrated by hot-rolling thin (0.110 in.) cast strips into sheet strips approximately 0.020 in. thick(1). However, the process used was characterized as being "somewhat specialized" and concluded that TAZ-8A was not "demonstrated to be a wrought alloy." In addition, TAZ-8A is a very hard, tough alloy that resists cutting and grinding operations unless diamond-edge cutting tools are used. The most practical method of fabricating parts of cast TAZ-8A is to precision cast the part to near-net shape and finish-grind it if necessary.
Because the material is a highly alloyed one, the casting process must be carefully controlled to prevent segregation of the constituents during solidification.

As part of the effort to reduce the workability and casting difficulties encountered with TAZ-8A, an investigation was made into extruding bars of the material from prealloyed powders(2). The powder was made by atomizing the molten alloy in an inert gas spray. The fine droplets of molten alloy were subjected to very rapid solidification, preventing segregation. The powders were sealed into evacuated mild steel cans and extruded directly into bars. The resulting bars had a very fine, homogeneous microstructure.

The extruded bars exhibited a curious reversal of properties compared to the cast TAZ-8A material. At temperatures below 1500F (830C) the extruded bars had considerably greater tensile strength than the cast bars, but at higher temperatures the cast bars were stronger. Heat treating the extruded bars to cause grain coarsening resulted in bars with tensile and stress-rupture properties that approached the as-cast bars but did not match them. The strength and stress-rupture properties of the extruded bars, compared to the cast bars, are presented in Figures 8, 9, and 10.

Notice that the stress-rupture data in Fig. 10 is for heat-treated extruded bars. Stress-rupture data were unobtainable for the as-extruded bars because under the controlled conditions of the stress-rupture test they exhibited superplastic behavior. After four hours at 1900F (1038C) and 1000 psi (6.89 MN/square meter) the as-extruded TAZ-8A specimen had an elongation of over 600 percent without rupturing. At that point the test apparatus was at its maximum travel.

This superplastic behavior suggests one approach to forming parts from TAZ-8A. In a subsequent test involving hot pressing the extruded powder material under low strain rates a cylindrical specimen 9/16 in. (1.4 cm) diameter and 5/8 in. (1.6 cm) high was reduced in height by 75 percent without cracking(2). However, when attempts were made to form the material at high strain rates, such as are encountered in conventional rolling and stamping operations, the material cracked. These results indicate that bars extruded from TAZ-8A powder can be "wrought" providing slow strain (deformation) rates are used and the formed product then heat-treated to "set" it. The heat-treated extruded bars did not exhibit superplastic behavior; they behaved similarly to the cast specimens.

The high cost of TAZ-8A alloy compared to the common iron base alloys, combined with the rather specialized fabrication procedures required to work this material, limit its use to relatively small parts if they are made of the solid alloy. This has led to investigations of using the material as a high-temperature protective coating applied to less expensive substrates. Used in this manner its properties of exceptional thermal shock resistance, oxidation resistance and abrasion resistance can be transmitted to large complex machine components while performing the difficult machining work on the more easily worked and less expensive substrate.

At the present, two techniques for applying TAZ-8A coatings to various materials have been investigated: plasma spray coating and plasma vapor deposition (PVD). The resulting coatings have not been fully characterized, but some preliminary results can be reported.

Plasma spray techniques developed by NASA can deposit layers of TAZ-8A up to about 20 mils thick. When thicker coatings were attempted, the plasma spray became unstable and the coating would separate from the substrate. The resulting surface is rough but can be ground smooth. The plasma sprayed layers are porous and include metal oxides dispersed throughout the coating layer (a consequence of spraying molten alloy in air). It has not been quantitatively determined what effects these encluded oxides have on the properties of the coating. It may be that for certain applications they may have a beneficial effect; for example, they might improve the abrasion resistance of the coating. In test applications so far, these oxides do not appear to adversely effect the performance of the coating.

The porosity of the plasma spray coating means that this material will not protect the substrate material from corrosion. In one preliminary test of a steel component with a plasma spray coating of TAZ-8A, subjected to a very high temperature environment with water spray cooling, the water penetrated to the base metal and corroded it, causing the TAZ-8A layer to spall off. At the time of coating separation, the test part had lasted in service ten times as long as the standard uncoated part.

Technicians at the NASA Lewis Research Center have plasma vapor deposited TAZ-8A coatings on a variety of materials, including stainless steel, fiberglass, glass, and ceramic materials such as Space Shuttle thermal protection tiles. PVD coatings up to 2 mils thick have been applied; since the PVD process is time-dependent, thicker coatings would not be economical by this process.

The PVD coatings produced so far have been observed to be clean, very dense, with a very fine microstructure. The grains are very thin, closely packed, and aligned perpendicular to the surface being coated. They appear to be very high strength in the direction perpendicular to the surface, but there is some preliminary evidence that the coating layer may readily "cleave" along grain boundaries. This may be prevented by heat treatment to realign the grain structure and coarsen it. Preliminary results also indicate these PVD coatings have excellent tribological properties. When applied to smooth surfaces these PVD coatings appear to be highly reflective, suggesting their possible use as a high temperature, corrosion-resistant, abrasion-resistant mirror surface. Surface imperfections appear to be transmitted through the coating with no "blending out," suggesting use as a coating for die casting dies.

COMMERCIAL APPLICATIONS OF TAZ-8A

The Technology Utilization Office at the NASA Lewis Research Center is engaged in several Technology Applications Projects in which TAZ-8A is being investigated as a solution to problems inherent in some high temperature industrial process. These specific projects are still in preliminary stages, but they offer insights into the technical needs of such industries, and thus into potential applications of materials such as TAZ-8A. In addition, properties of this material in its various forms (cast, extruded powder, plasma spray or PVD coatings) that have been investigated also suggest potential applications.

The aerospace industry routinely casts superalloy materials into complicated, precision shapes such as turbine blades for jet engines. Precision casting techniques such as investment casting appear to be the best way to fabricate solid machine elements. Cast TAZ-8A alloys are extremely tough and resistant to normal cutting-type machining operations such as milling. Grinding and abrasive cutting using diamond tools are required.

This hardness, while a liability during the fabrication of a part, may become an asset, as the component will be highly abrasion resistant. A number of industrial process environments are both high-temperature and very abrasive. An example is glass making. The "chill blocks" used to cut glass sheets and tubes in several processes might be likely candidates for making from TAZ-8A.

The cost of the material and the casting processes (inert gas or vacuum casting) at present would limit the size of such parts to fairly small sizes. Some larger pieces could be fabricated from extruded powder bars by superplastic deformation, although the slow strain rates required for this will result in long fabrication times.

Thermal fatigue failures often propagate from surface cracking or crazing at the point of exposure to high temperature; this could be prevented or at least delayed by applying a high temperature protective coating. Using TAZ-8A as a coating applied to components fabricated from lower cost, more easily machined materials reduces the amount of TAZ-8A needed, eliminates many of the fabrication problems, and permits using this material on large parts. Advanced ceramics and ceramic composites have been proposed for similar applications. Superalloys such as TAZ-8A still appear to be more physically tough and resiliant, and able to withstand considerably more and more extreme thermal cycling and shocking than ceramic materials.

Several ongoing applications projects being conducted by the Lewis Technology Utilization Office are using this approach to attempt to solve thermal fatique problems in the machinery used for the continuous casting of steel. Also, the abrasion resistance and thermal shock resistance of TAZ-8A has led to an investigation into seeing if it could solve problems of die wear and shot sleeve erosion in the die casting industry.

To date, the two coating techniques investigated are plasma spray coating in air and plasma vapor deposition in a reduced atmosphere. The plasma spray coating process can produce a thicker coating, but the surface is rough and has to be ground if a smooth surface is required. This limits surface shapes to those that can be ground. The coating is porous; if the operating environment can attack and corrode the substrate material, some sort of impervious seal coat would be necessary. The PVD technique produces a very dense, impervious coat of TAZ-8A; this makes it a candidate seal coat. PVD also is the most promising technique for coating die casting dies, as it lays down a very smooth surface that replicates all details of the substrate surface.

A wide variety of materials has been successfully coated with TAZ-8A using the PVD process. Among them are stainless steel, glass, and ceramics such as the Space Shuttle tiles. It is felt that high temperature polymers such as PMR-15 are also likely candidates for coating with TAZ-8A using PVD. On smooth substrates, very smooth, highly reflective mirrorlike coatings of PVD TAZ-8A have been achieved. While the reflectivity of these TAZ-8A coatings haven't been quantitatively measured, the preliminary results suggest that this material could be used to produce mirrors for high temperature, abrasive environments.

Another potential application that as yet has not been explored is high temperature bearings. The PVD coatings appear to have very good tribological properties, and the extreme resistance of the cast alloys to machining also suggests this application.

Thicker coatings than those achieved by plasma spraying or PVD would probably have to be made by bonding a thin, extruded powder sheet of TAZ-8A to the substrate, using a bonding technique such as furnace brazing. The TAZ-8A sheet could be molded to a complex substrate shape using superplastic deformation, with subsequent heat treatment to "set" it.

The fabrication and processing techniques developed so far to work TAZ-8A do not lend themselves to mass production at the volumes associated with consumer goods. Rather, it is anticipated that realistic commercial applications of this material will be limited to solving temperature and abrasion-related problems in industrial process machinery. Each potential application will have to be carefully evaluated as to whether the increase in operational life of a critical part justifies the expense and fabrication problems.

CONCLUSIONS

The nickel base aerospace superalloy TAZ-8A has several properties that suggest its potential application to solve a number of industrial process problems. These properties include high temperature strength, oxidation resistance, thermal cycling resistance, and abrasion resistance. Applied as coatings to critical machine elements, TAZ-8A has the potential to dramatically extend the in-service lives of parts exposed to high temperature processes.

REFERENCES

1. Waters, W.J. and Freche, J.C., 1966, "Investigation of Columbium-Modified NASA TAZ-8 Superalloy," NASA Technical Note D-3597.

2. Freche, J.C., Waters, W.J. and Ashbrook, R.L., 1969, "Evaluation of Two Nickel-Base Alloys, Alloy 713C and NASA TAZ-8A, Produced by Extrusion of Prealloyed Powders," NASA Technical Note D-5248.

TABLE I. COMPOSITION OF TAZ-8A

CONSTITUENT	NOMINAL COMPOSITION, WEIGHT PERCENT
Tantalum, Ta	8
Chromium, Cr	6
Aluminum, Al	6
Molybdenum, Mo	4
Tungsten, W	4
Columbium, Cb	2.5
Zirconium, Zr	1
Carbon, C	0.125
Boron, B	0.004
Nickel, Ni	Balance

Unnotched Charpy Impact Resistance 24 ft-lb at Room Temperature

TABLE II - Comparison of Oxidation-Affected Zone Depths of Argon-Melted and Vacuum-Melted TAZ-8A

ALLOY	EXPOSURE CONDITION		EXTERNAL SCALE THICKNESS, MILS	DEPLETION ZONE THICKNESS, MILS	TOTAL AFFECTED DEPTH, MILS
	TIME, HOUR	TEMP., F			
Argon-Melted TAZ-8A	310	1900	.1	.8	.9
Vacuum-Melted TAZ-8A	310	1900	.1	.3	.4

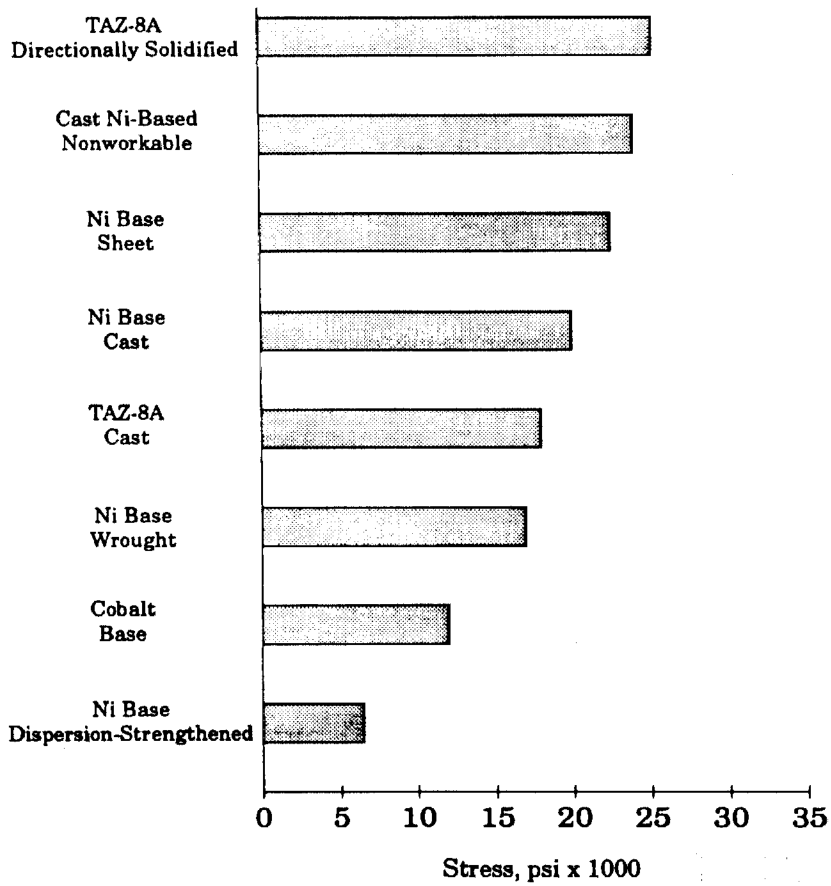

FIG. 1. - Stress to produce Rupture in 100 hours at 1800 F (1000C)

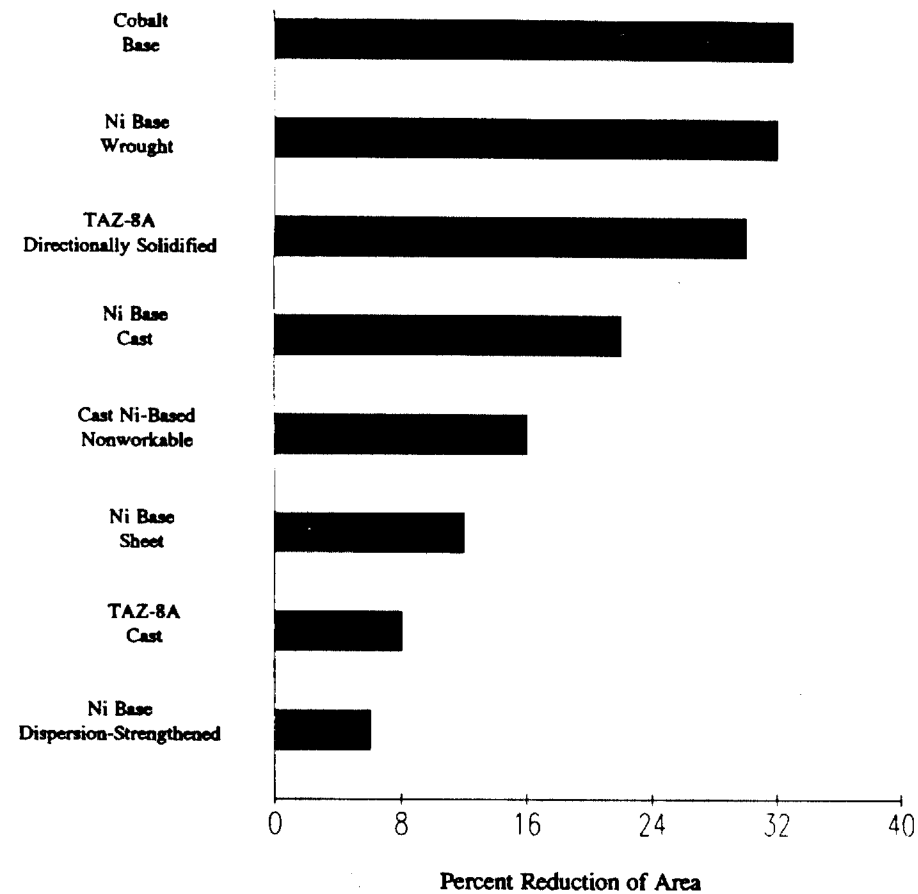

FIG. 2. - Stress-Rupture Reduction of Area at 1800 F (1000C)

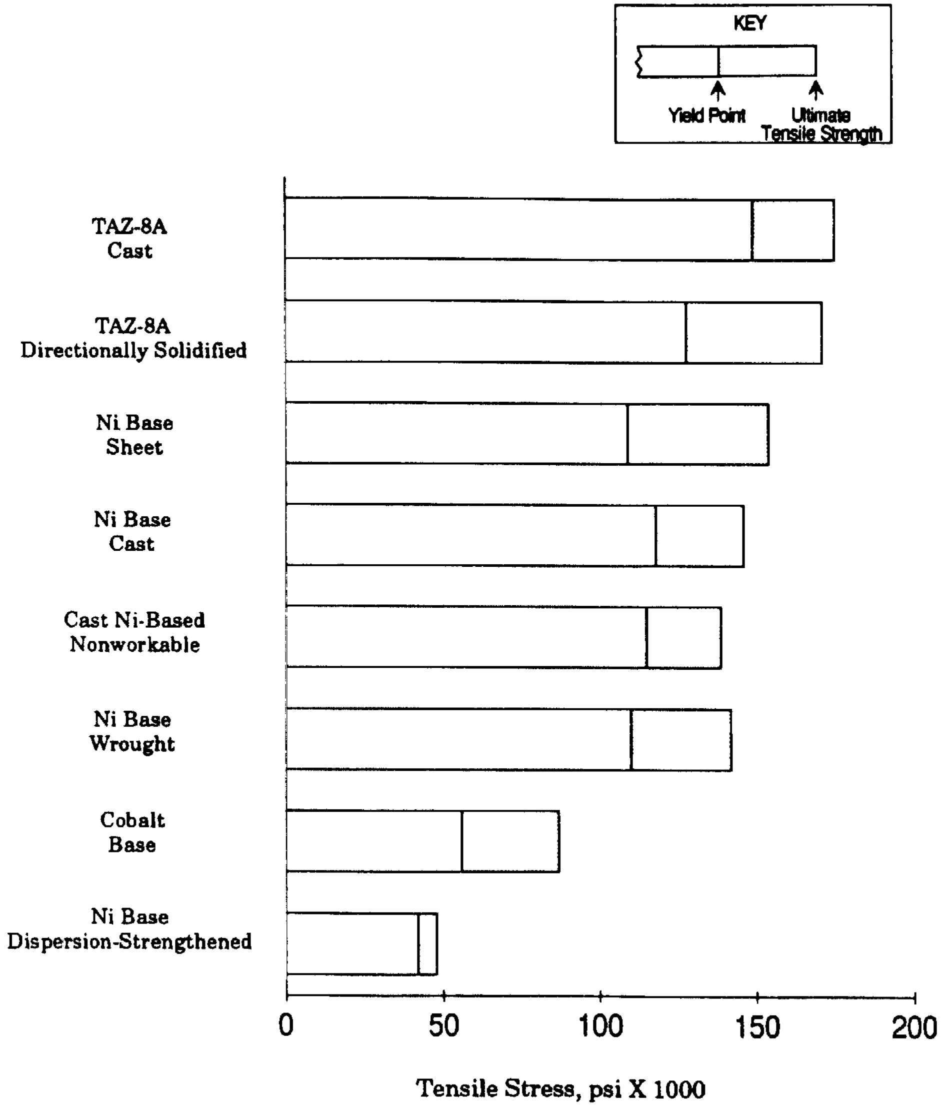

FIG 3. -Tesile Strength of Various Alloys at 1400F (775C)

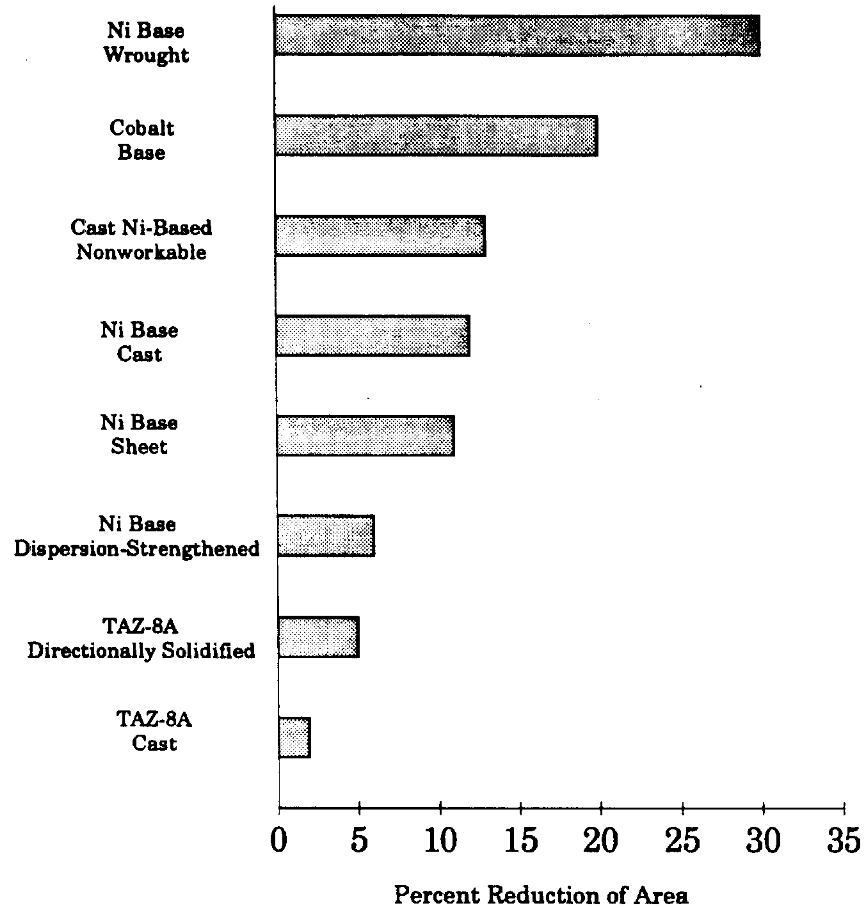

FIG. 4 - Tensile Reduction in Area at 1400F (775C)

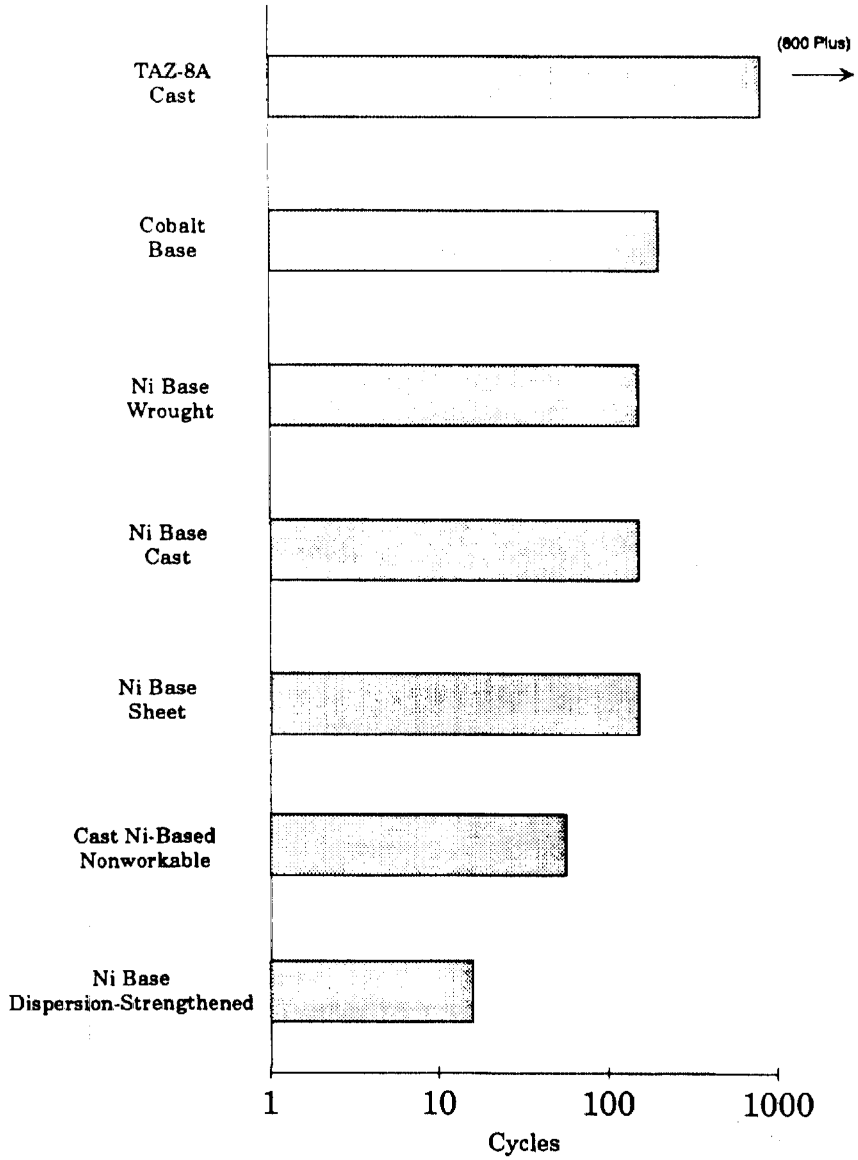

FIG. 5 - Thermal Cycles to Crack Initiation, Bed Temperatures 1915F-525F (1046C - 274C)

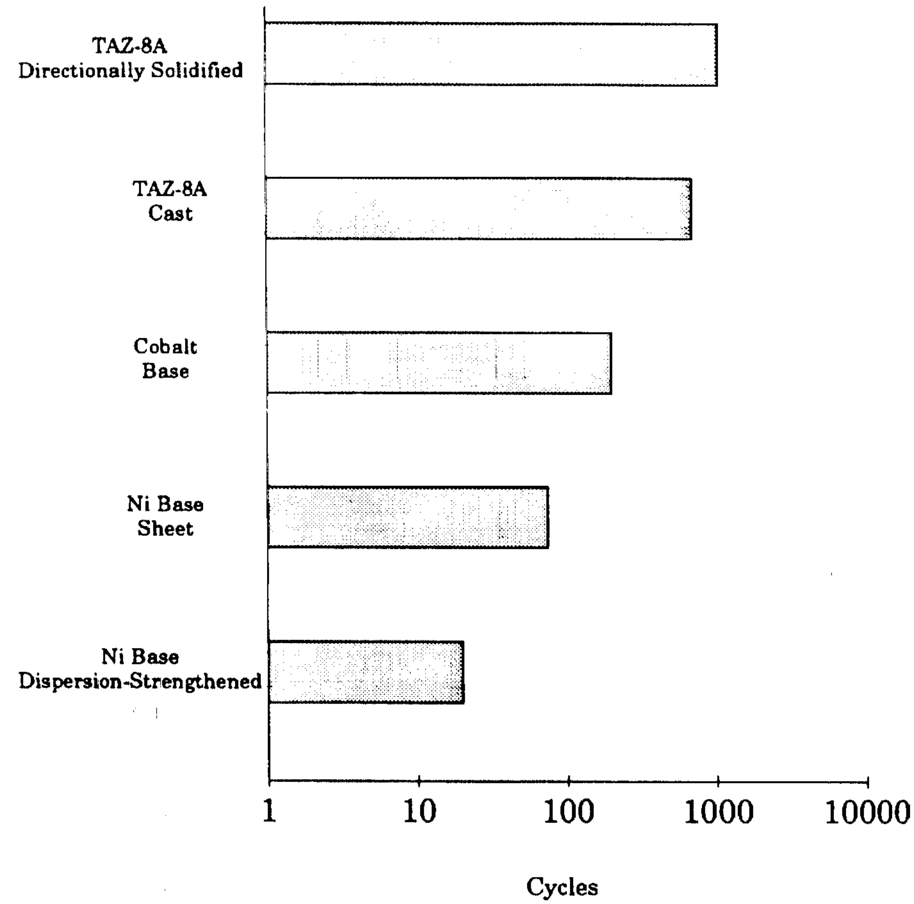

FIG. 6 - Thermal Cycles to Crack Initiation, Bed Temperatures 2065F - 675F (1129C - 357C)

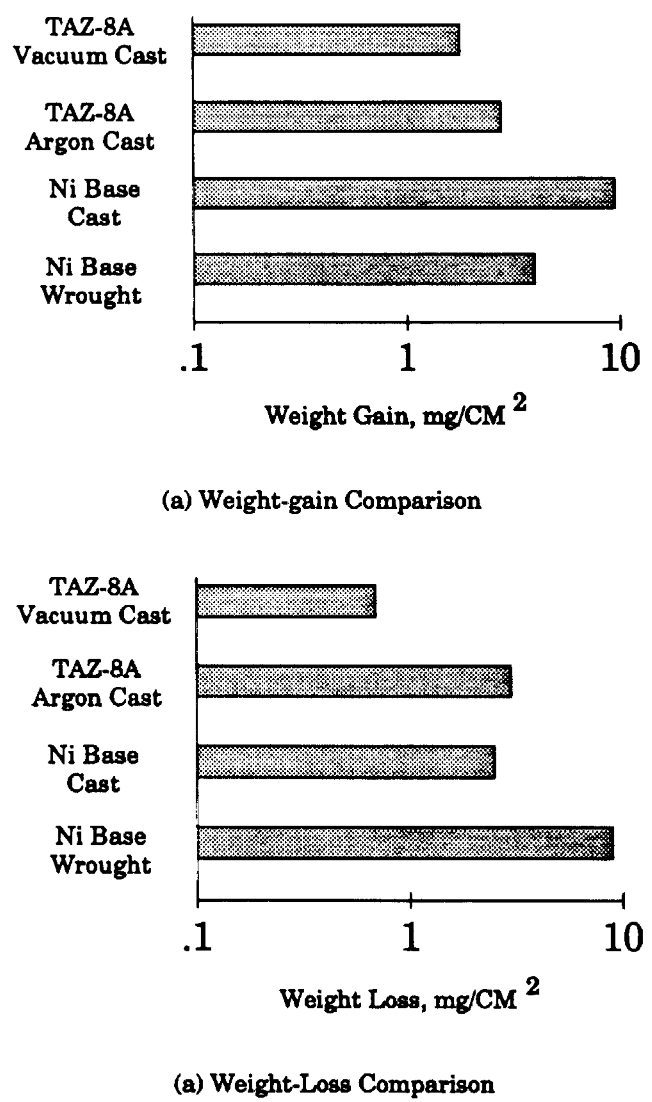

FIG. 7 - Oxidation Behavior of Several Nickel-Base Alloys at 1900F (1040C) after 310 Hours Exposure

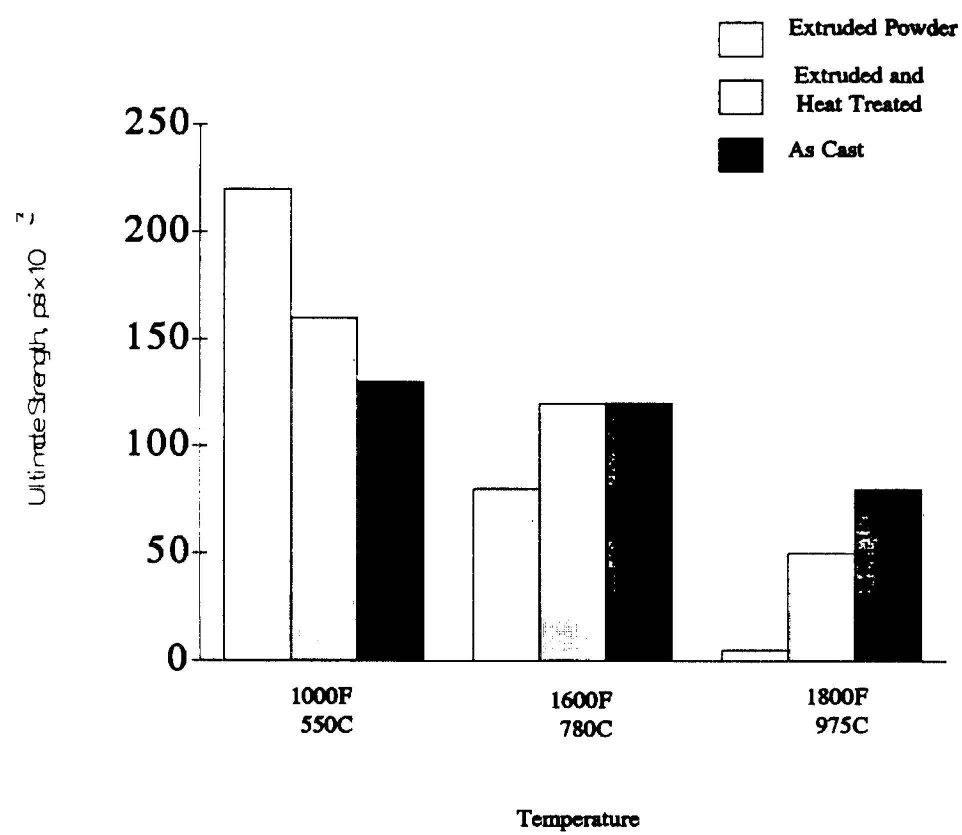

FIG 8. - Comparison of Tensile Properties of TAZ-8A Powder Products and As-Cast TAZ-8A

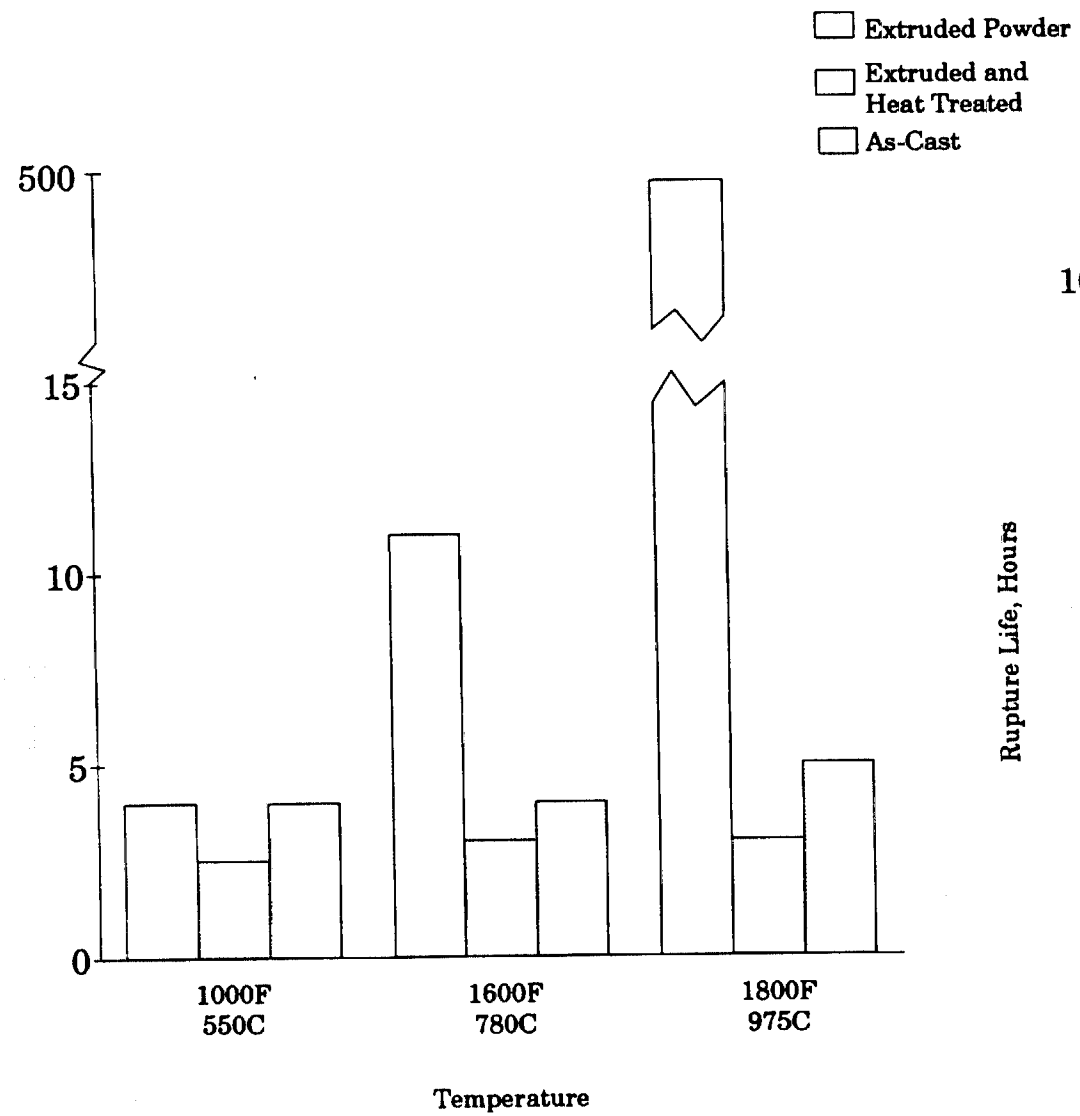

FIG. 9 - Percent Elongation at Tensile Failure of TAZ-8A Extruded Powder Products Compared to As-Cast TAZ-8A

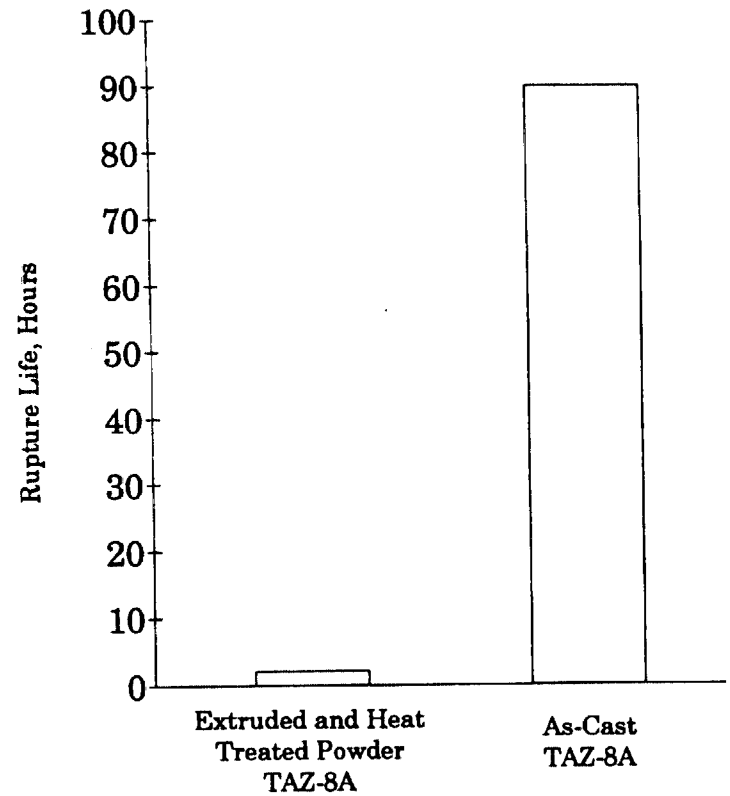

FIG. 10 - Comparison of 1900F (1038C), 15000 psi (103 MN/M^2) Rupture Lives for Extruded and Heat Treated Powder Product and As-Cast TAZ-8A

182